Design of a vertically deflecting Four Bounce Monochromator for the I20 XAS Beamline at Diamond Light Source

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Abstract:
The I20 XAS beamline at Diamond has a very challenging specification which has proven very demanding for the design and construction of the vertically deflecting four bounce monochromator. Energy selection is generally 2 orders of magnitude smaller at 1 in 10^6 than more typical hard X-Ray beamlines requiring 1 in 10^4. At this level of sensitivity, temporal and temperature stability effects over some hours have all proven very difficult to solve. The performance of capacitive sensors and piezo drives and their control loops have also been pushed to their limits. Heat bump effects and the cooling of the first crystal to allow it to handle up to 600W delivered from a Wiggler is also a significant challenge.

This paper describes some of the key design features of the crystal stages that have been recently designed and built into the monochromator as well as the air bearings that have been developed for the main Bragg spindle rotations. Preliminary results are described following recent tests with beam and some comments on the next steps.

1-Diamond Beamline I20

The I20 spectroscopy beamline at DLS is equipped with two branch lines. The Four Bounce Crystal Monochromator (4BCM) is installed on the XAS branch which delivers high spectral purity monochromatic X-rays for scanning X-ray absorption spectroscopy and for X-ray emission spectroscopy. The source is a 2m wiggler capable of delivering up to 600W of power to the 4BCM. The energy range of the beamline is 4keV to 34keV. Principal areas of interest for the beamline are catalysis, biology, environmental science and material science.

To cover the wide range of energies the 4BCM is fitted with 2 sets of crystals; Si(111) and Si(311). A general view of the instrument is shown in Fig.1.

The 4BCM has taken a number of years to develop[1]. The air-bearing Bragg axles were designed and developed to carry heavy crystal assemblies with very high precision. They have now been used very successfully in a number of

DCMs developed within DLS. Thermal management is another area where efforts are being made to optimise performance, particularly in the crystal cooling and clamping. The subject of this paper is principally the development of the stages to carry and manipulate the crystals.

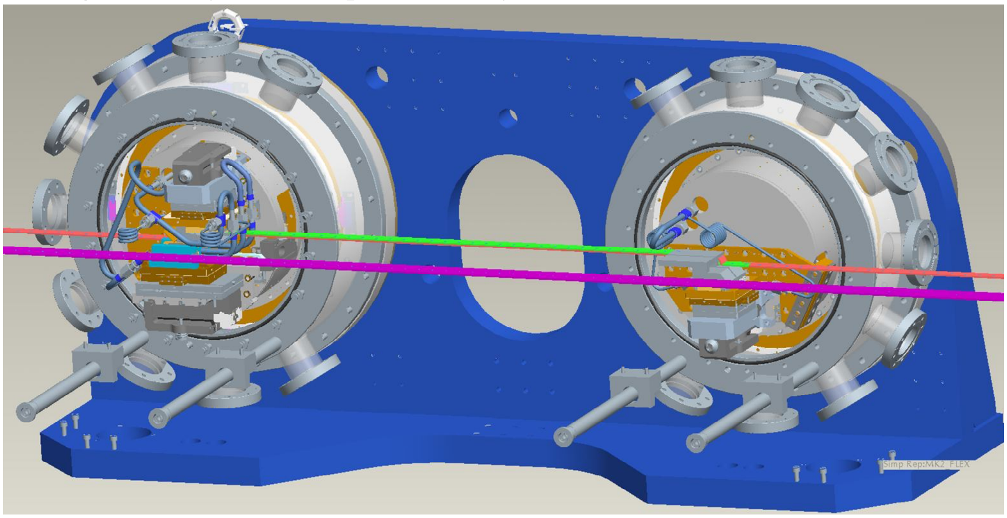

Figure 1. The 4BCM assembly

2-The crystal stages

The specification for the 4BCM is very tight to allow the four crystals to maintain their performance during scanning operations. The stages carrying the first and second crystals have to maintain their parallelism whilst the device is scanned through at least 2keV. At the extreme this implies a maximum droop of +/-100nrad/degree of Bragg rotation. The high thermal load also implies extremely stiff stages to resist the forces imposed due to the mass of the crystals, the stiffness of the cooling pipework and vibrations induced by the LN2 flow. All four crystals are LN2 cooled. The first crystals are side clamped whilst the second and the channel-cut crystals 3/4 are base clamped. LN2 flows through separate heat exchangers for each pair of crystals.

The LN2 is carried to the stages in solid copper pipes to avoid any additional sources of turbulence, but this implies that the stages must be driven with sufficient force that the pipes can be distorted through the full range of movement.

Motions have been kept deliberately small to allow sufficiently high resolution and also sufficiently high forces to be applied. The first crystal is adjustable in pitch, with a full range of 3mrad and a resolution of 90nrad, while crystal 2 is adjustable in roll with a full range of 5mrad, as is the channel-cut crystal on axle 2.

Piezo stacks from Piezosystem Jena drive all three crystal stages, with feedback being provided by Micro-Epsilon capacitive sensors.

The piezo stacks were chosen for their high stiffness and large range of movement (100micron), as well as the availability of a commercial power supply offering sophisticated control with remotely configured PID loops, filtering and other parameters. The capacitive sensors are also supplied with a sophisticated controller with analogue and digital outputs.

Initial analysis of a simple flexure hinge based system with the piezo acting directly on the main flexure showed that the stresses inside the flexure would cause problems for the system to meet the exacting specification. As a result the system has been designed to use a two flexure system as shown in Fig.2. The main flexure is a simple hinge fabricated from a single piece of Invar. This gives us a very predictable stage which carries the crystals and the capacitive sensor. In order to amplify the range of motion of the piezo a second flexure system (the amplifier flexure) carries the piezo, springs and damping components. This amplifier flexure is a key part of the design as it minimises the stresses within the main flexure. It is constructed of aluminium and stainless steel as its stability is not so critical to performance due to its lying within the control loop.

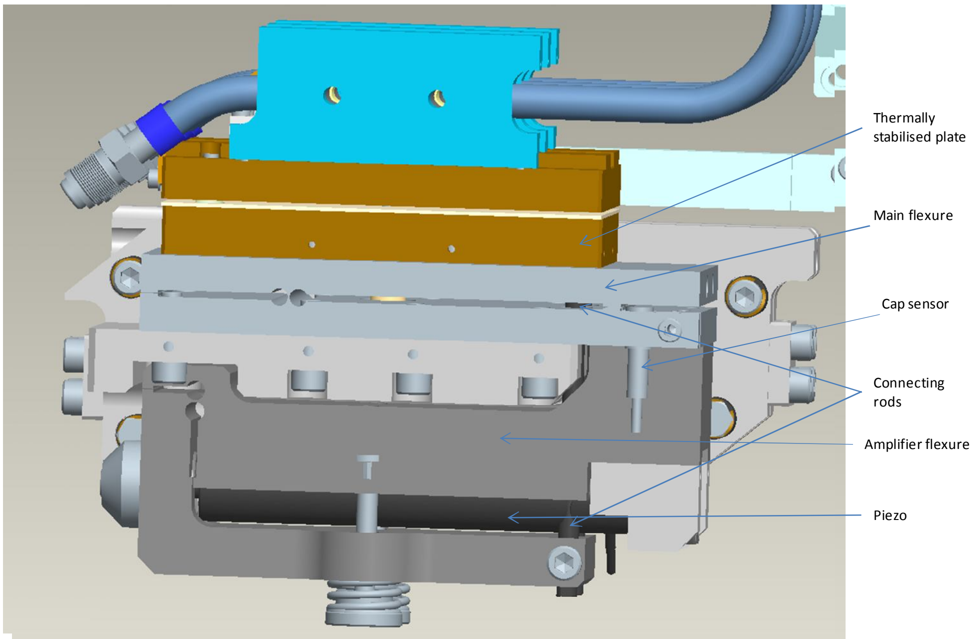

Figure 2. The first crystal pitch stage

The amplifier flexure output is connected to the main flexure by a third flexure system in the form of a forked rod. This allows the parasitic motions of the rotation of the amplifier flexure to be absorbed. It also offers an easy point of adjustment for the alignment of the stage.

The capacitive sensor is held in a split clamp in the static part of the main flexure and 'views' directly the moving part of the main flexure.

A further advantage of the amplifier flexure was to allow us the freedom to position the piezo actuator within the small vacuum vessel available. The four-bounce configuration implies that space is at a premium, and the vacuum domes are significantly smaller than those normally used in a more traditional DCM.

The whole stage assembly is mounted to a substantial tee-shaped Invar plate which, in the case of the pitch stage, features a stiff hinge to allow the roll of the assembly to be set during installation but offering high stiffness during operation.

To the top surface of the main flexure is bolted a copper plate with a heater to allow it to be thermally stabilised. This minimises the time required for the system to stabilise when input power is varied and further helps to ensure the stability of the system. Above this plate the cold copper plate holding the crystals is isolated by three glass balls in stainless steel seats to provide thermal isolation and kinematic mounting.

The three stages were subjected to an exhaustive set of bench tests prior to installation in the 4BCM. Range, resolution, hysteresis, parasitic motion and linearity were compared to data from an auto-collimator. A straingauge was used to measure stage stiffness, and software was developed to allow vibrations to be assessed for amplitude and frequency. The control loops were also optimised during the bench testing.

3- The control loop

The control loop (Fig.3) is closed locally at high speed using the analogue output from the capacitive sensor while Epics is used to provide a slower external loop using the high resolution digital output. The range of the capacitive sensors is 500micron.

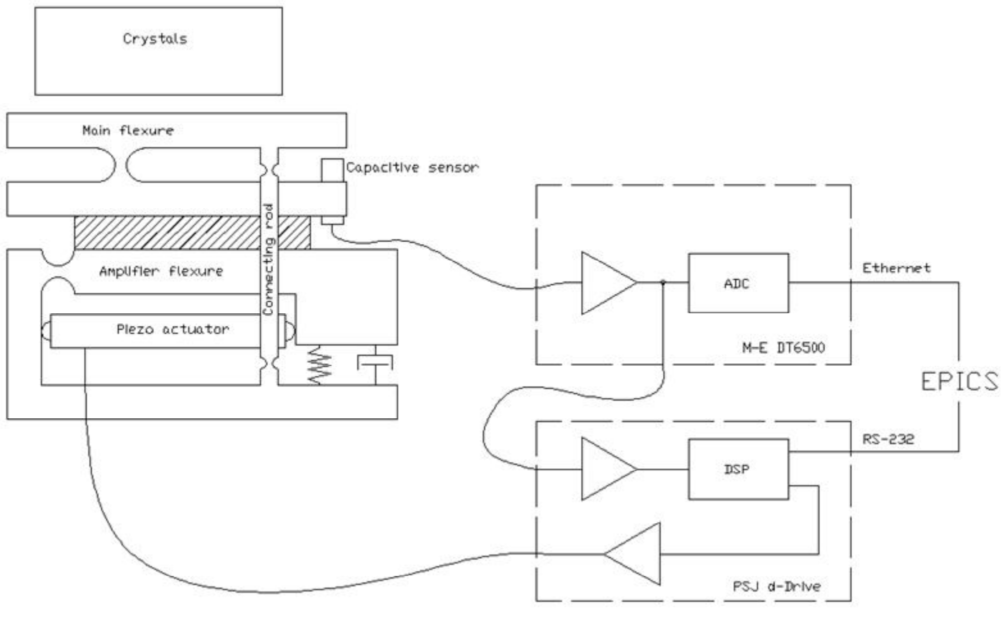

Figure 3. Schematic of the control loop

The connection between the capacitive sensor controller and the piezo controller is an analogue 0-10V signal. This allows the maximum bandwidth of the piezo to be utilised. A high resolution (24-bit) ADC within the capacitive sensor controller allows digital communications to Epics, and this signal is used to provide a low speed ‘supervisory loop’ around the fast loop. We have found that this output is somewhat more stable over time so the Epics loop updates the setpoint within the piezo controller to maintain the best possible stability.

For testing and vibration analysis the Ethernet output from the capacitive controller is taken instead to a Windows PC as described in the following section.

The DSP stage within the piezo controller provides fast processing of feedback data with a range of controllable parameters. Amongst these are options to limit the bandwidth or to add notch filters to avoid stage resonances. By careful adjustment of the mechanical damping components during the bench tests we were able to remove these filters without introducing instabilities.

4- Software and testing

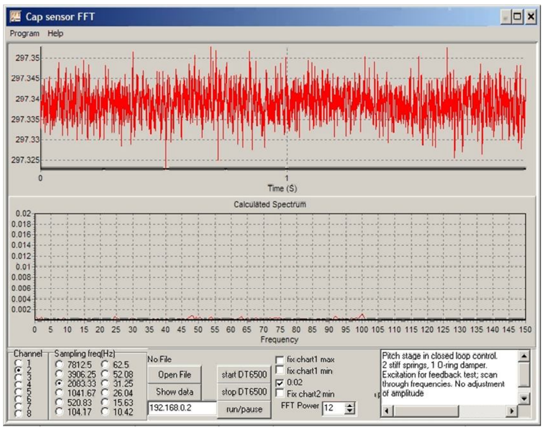

Figure 4. FFT software window. Data is taken 'on the bench'. No excitation. Units of microns

In order to assess the stage performance we have written a Windows software package which allows fast sampling of the capacitive sensors (Figs.4 & 5). Data is acquired at up to 2kHz with sub-nm resolution and displayed in real-time. A discrete Fourier transform is also applied to the data in real-time and displayed in a second panel. This panel allows the magnitude of specific frequency elements to be identified and, therefore, addressed. In our case it easily allows the natural frequencies of the stages to be identified and immensely simplifies the task of identifying sources of unwanted vibrations. A second, but significant, use of the software is in the optimization of the piezo control loop. This is an important part of the stage performance as it allows the piezo to correct for small motions to the maximum frequency of which it is capable.

In order to further improve the stability performance of the pitch stage we have the option of including intensity feedback from a monitor placed after the second crystal. This feedback loop requires that the pitch stage can be deliberately oscillated through a very small angle at a frequency which is chosen to be high enough that any resulting intensity variation will be averaged out over the shortest conceivable sampling period. Using our FFT software we

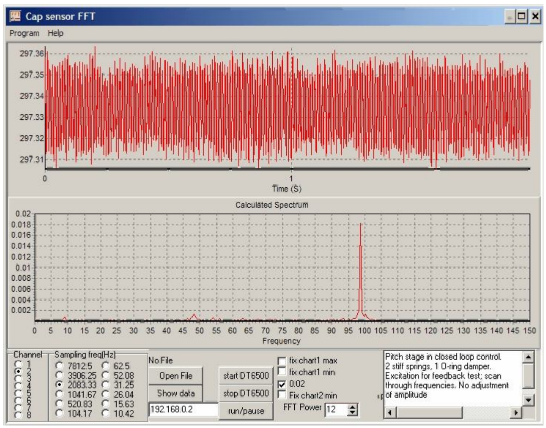

Figure 5. Showing a clear single peak at the excitation frequency of 100Hz for feedback.

were able to demonstrate that any frequency up to 120Hz can be used with the pitch stage without exciting any other resonances. In Fig.5 an oscillation of 18nm is clearly visible at just below 100Hz. This represents a 320nrad pk-pk oscillation at the crystal. In practice, the oscillation used is a larger amplitude than this at around 75Hz. The monitor is a diode inserted between the two axles.

5- Testing with X-rays

Fig.6 shows the first axle stages after assembly. The 4BCM has been tested with

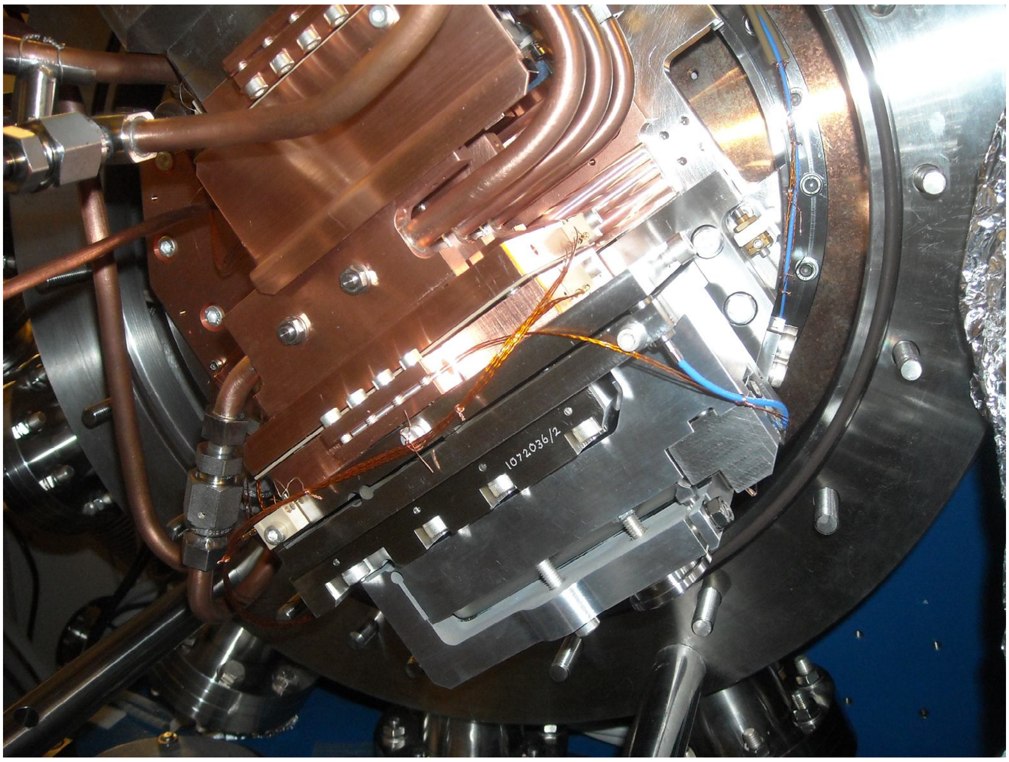

Figure 6. The first crystal pitch stage in situ with Compton shields etc

X-Rays at powers up to around 400W and the Si(111) crystal set gives acceptable performance but the Si(311) first crystal cooling efficiency is not as good as the Si(111) and poor clamping of the Indium layer is suspected.

A first user is scheduled by end 2012. Further testing and development are planned to further improve cooling efficiency of the first crystals in order to take the full 600W with acceptable heat bump slope errors. This still remains very challenging for the Si(311) which will operate up to 34keV requiring the most precise parallelism to be maintained of +/- 0.2 micro-radians.

References

[1] G.Duller, J.Kay, X.Liu, S. Diaz-Moreno, J.Sutter, B.Nutter, B.Dobson, A High Precision, High Stability, Four Bounce Monochromator for Diamond Beamline I20, MEDSI proceedings 2008